Characterizing MoS_2-Si p-n Heterojunction Using Laser Terahertz Emission Spectroscopy

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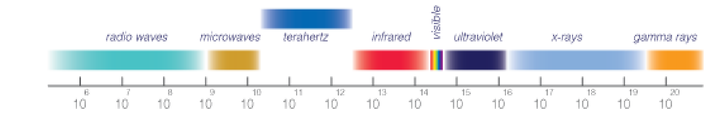
Introduction

The "Terahertz Gap"

- Spectral region 0.3 – 3.0 THz (1 mm - 100 μm)



- Final frontier for improving optoelectronic and electronic devices
  - Low energy usage

Atomically thin two-dimensional (monolayer/2D) materials differ significantly from bulk (3D) counterparts

- Van der Waals bonds (2D) vs. covalent bonds (3D)
- MoS_2 characteristics
  - Direct band gap of 1.8 eV (2D) vs. indirect band gap of 1.3 eV (3D)
  - Stable charge exciton state at room temperature (2D)
- Unique applications for optoelectronic and electronic devices

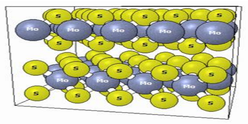


Fig. 1: Atomic structure of MoS_2

Fig. 2: Bulk MoS_2 sample

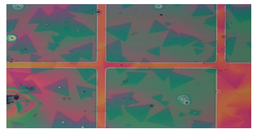


Fig. 3: Monolayer MoS_2 sample

Objectives

Investigate 2D-3D heterojunction MoS_2-Si

- n-type (electron majority carrier) monolayer MoS_2 and p-type (hole majority carrier) bulk Si

Gain new insight into the nature of the MoS_2-Si p-n junction energy states

- Band alignment
- Band bending

Understand how the properties of 2D-3D junctions differ from those of conventional 3D-3D junctions

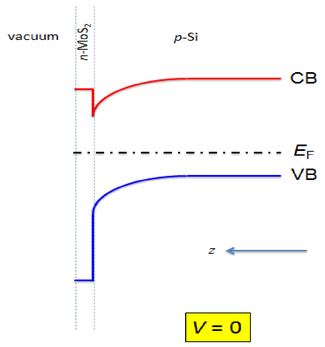


Fig. 4: Band diagram of MoS_2-Si heterojunction[1]

Methodology

Laser Terahertz Emission Spectroscopy and Imaging

- Sensitive to electric fields in MoS_2-Si heterojunction
  - Map out distribution of electric fields (band bending)

Optical Imaging

- Determine resolution of system
- Optimize alignment of system in order to perform terahertz imaging

Methodology

Terahertz Imaging

- Determine if there is terahertz emission from MoS_2 p-n heterojunction

Raman Microscopy and Spectroscopy

- Monitor the deterioration of MoS_2 p-n heterojunction and categorize different materials within the sample

Framework

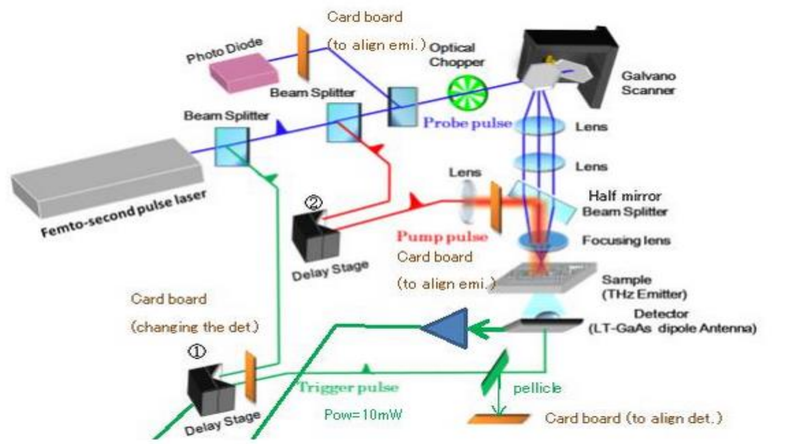


Fig. 5: Schematic of terahertz system setup

Results and Discussion

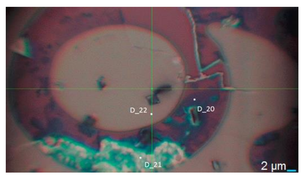
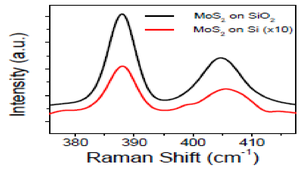
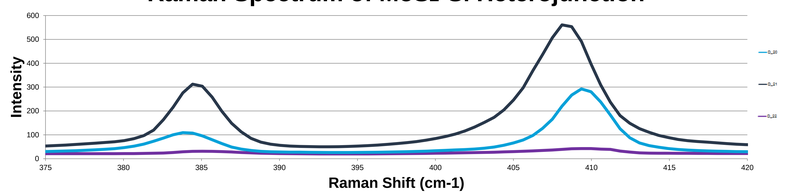


Fig. 6 (left): Raman spectroscopy sampling areas of MoS_2-Si with PMMA removed

Fig. 7 (right): Previously found Raman peaks of MoS_2 on silicon and silicon dioxide[1]



Raman Spectrum of MoS_2-Si Heterojunction



D_20 and D_21 have Raman peaks characteristic of monolayer and bulk MoS_2 respectively

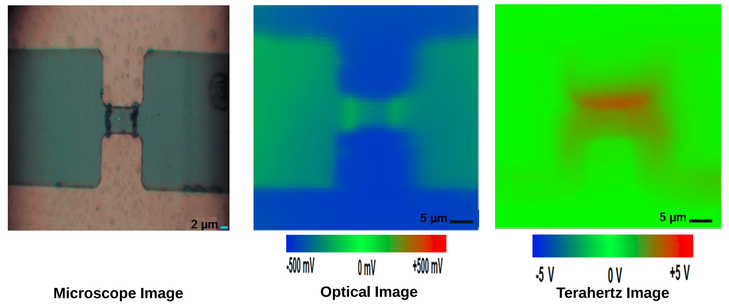
D_22 has Raman peaks characteristic of silicon only

Fig. 8: Furthermost left image is of the sample freshly prepared. The other two images are of the sample one month later. All images are magnification X100. The furthermost right two Images were acquired using Horiba XploRA ONE Raman microscope.

Results and Discussion

Current alignment and resolution of system

- Photoconductive antenna



Microscope Image | **Optical Image** | **Terahertz Image**

Image of photoconductive antenna is distinguishable

Microscope Image | **Optical Image**

Optical image can discern outline of number

- However, cannot detect monolayer Raman spectroscopy-confirmed MoS_2 (D_20) on "9"
- Resolution is not good enough for terahertz imaging

Conclusions and Future Work

Finer tuning will be required to achieve higher quality optical images and terahertz images

- Currently resolution is ~5 μm
- Resolution up to ~1 μm achievable

Delay the deterioration of p-n junction

- Determine the thickness of resultant bulk MoS_2 layers
- Understand why oxidization of silicon results in conglomeration of MoS_2

Reference

[1] Bo Li et al., in preparation

Acknowledgments

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